Essential Oil Crops for Sustainable Agriculture – A Review

Alessandra Carrubba and Caterina Catalano

Abstract Multifunctionality and diversification of farming systems, integration of agricultural practices with the non-agricultural productive systems operating on the territory, biodiversity safeguards, and reduction in off-farm inputs, are key factors for all modern development strategies in agricultural areas. Such issues are valid worldwide, but are especially true in areas in which the cultivation of the more widespread and "classical" crops is constrained by factors of varying degree and importance. In Mediterranean areas, where many environmental and economic factors often reduce rural areas to marginal conditions, the search for new crop opportunities has become one of the newest topics in agricultural research. In this review, we focus on the state-of-the-art cultivation of essential oil crops, in Mediterranean environments with a special interest in herbs. The following are the major points of our analysis. (1) Growing such crops as specialized cultivations, especially for species native to the selected environments, is the only practical and sustainable way to obtain naturally derived raw matter for both industrial and domestic purposes. (2) Most essential oil crops are suitable for many different uses, and fully adaptable for transformation even by small, local manufacturers. (3) In many cases, they may be grown with environmentally friendly or organic techniques; this enhances their environmental compatibility and also gives them an additional economical advantage, raising their chances to be addressed in the emerging market sector of "natural" products. Our conclusion is that crops grown for the extraction of economically valuable essential oils may be a strategic resource for many environments, even marginal, and that there is scope for farmers to improve the cultivation of such species on arable land. There is room, however, for many agronomic and economic questions to be studied in future experimentation and research.

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1 Introduction

In recent times, a deep interest has been addressed worldwide to the search for "new" crops, to be allocated to farming systems in which traditional crops are losing competitiveness, and also meant as a diversification option for farmers who want to increase their income (Prohens et al., 2003). To be successful, a "new" crop must meet a number of conditions: first, it must be economically reliable; second, it must be grown using the minimum amount of off-farm technical inputs as possible; and third, it should find a place in an "integrated" scheme, i.e., a planning strategy including both agricultural and external commodities, with a special interest in diversified production opportunities such as cottage industries, on-farm processing, agribusiness, recreation, tourism, and so on (UN-ESC, 2008).

The advantages of crop diversification, both in space and time, are many, and they include a better exploitation of land resources, lower risks from pests and diseases, and a higher stability in yields and income (Altieri, 2004; Prohens et al., 2003). In areas where environmental constraints set a limit to agricultural management, this issue takes a special importance. In many Mediterranean areas, a number of climatic limiting factors may be of concern. Prolonged dry periods in summer and spring with a high seasonal evapotranspiration demand, and lack and poor quality of irrigation water, bring as a consequence a growing tendency to soil salinization; rainfall mostly occurring in winter, often as intense rainstorms, may cause the breakdown of soil structure and lead to soil erosion (Arnon, 1992). In recent times, attention was called on the expected overall worsening of this scenario due to anthropogenic climate warming, whose effects would be more severe for farming systems currently located in marginal areas (Olesen and Bindi, 2002). Under these conditions, the options for farmers are often limited, and the growing difficulties for agricultural entrepreneurs have led in many cases to the abandonment of the territory.

Our basic idea is that the cultivation of crops for the extraction of economically valuable essential oils may be, in this context, an interesting option. Here we review some of the major points related to the introduction of essential oil crops as alternative cropping opportunities, with a special emphasis on their potential role for sustainable agriculture in Mediterranean environments. The major advantages and constraints to cultivation are discussed, together with the genetic, technical, and environmental factors that exert some effect on essential oil yield and quality. Some examples are given about the technical solution that are, or could be, used in Mediterranean environments and for Mediterranean essential oil crops, in order to optimize yields and quality features.

1.1 Producing Essential Oils

Essential oils are volatile mixtures of different liposoluble organic substances, most of which are aromatic, and include alcohols, aldehydes, ketones, and so on. They are produced by plants in variable quantities and may be easily extracted by means of simple distillation processes. Although the major use of essential oils worldwide is for flavoring purposes, they also have a number of important industrial and domestic uses linked to their specific actions. As an example, rosemary oil is claimed to have simultaneous insecticidal (Katerinopoulos et al., 2005), antioxidant (Etter, 2004), fungicidal (Pauli and Knobloch, 1987), antimicrobial (Pintore et al., 2002), and even hypoglycemic (Mentreddy et al., 2005) activity. Therefore, there would be interest in sectors in which one, or more, of such activities are of use.

The European chemical industry annually imports a great deal of essential oils: the FAO statistic bulletins report that more than 52,000 tons of essential oils (terpeneless or not) were imported in 2005 by France, Germany, the United Kingdom, Netherlands, and Italy (FAO, 2007). The major sources of this massive amount of essential oils were the USA, Brazil, China, and India, accounting for over 50% of the total imports. However, it is worth noting that this partition of supply does not match the monetary exchange. For example, the USA produced 10.7% of the sold oil and received 16% of the corresponding value in dollars, whereas Brazil produced 26.9% of the oil, but only received 5% of the related monetary value.

There are basically three ways to produce essential oils: the collection of plants from the wild, their cultivation ad hoc, and,recently, their extraction from callus or tissue cultures. The first method, largely used in earlier times, is obviously limited to small supplies and local uses. First, collecting plants from the wild does not guarantee the quantitative and qualitative uniformity requested by industry (Ruta et al., 2006; Shetty et al., 1996). Second, in many cases, overharvesting caused severe environmental impacts, resulting in a loss of biodiversity (Schippmann et al., 2002; Skoula, 2006; WHO, 2003) and in the depletion of spontaneous populations, such as reported for rosemary in Sardinia (Mulas and Mulas, 2005).

The production of essential oils by means of biotechnology seems to be the most promising way to meet the exigencies of industry. Genetic engineering, micropropagation, tissue culture, and in vitro regeneration could reach the objective to produce, stabilize, and quickly propagate plant materials containing oils with a given composition or flavor, or even to produce selected secondary metabolites (Weiss, 1997). Much effort has been invested in these areas, and the results are often satisfactory, such as for mint (Tariqul Islam et al., 2003), some *Salvia* species (Olszowska and Furmanowa, 1990; Savona et al., 2003; Santos-Gomes and Fernandes-Ferreira, 2003; Scarpa et al., 2006), thyme (Iapichino et al., 2006; Shetty et al., 1996), rosemary (Gatti and Predieri, 2006; Misra and Chaturvedi, 1984), lavender (Lucchesini et al., 2003) alkanet (*Anchusa officinalis* L.; Su et al., 1994), periwinkle (*Catharanthus roseus* L.; Hirata et al., 1994), *Coleus* spp. (Petersen, 1994), myrtle (*Myrtus communis* L.; Rigoldi and Satta, 2006), anise (*Pimpinella anisum* L.; Santos et al., 1998), and many others. Notwithstanding, such technologies are still at an experimental stage and many technical problems remain to be solved. These include the

Fig. 1 Many essential oil crops are native to Mediterranean environments, where they grow as significant landscape components. In the photo, *Rosmarinus officinalis* L. (at flowering) in association with *Erica multiflora* L. (at the end of flowering) in a dry riverbed in the Nebrodi mountain (NE Sicily). (*Photo: R. Bontempo*)

stability of production, the occurrence of autotoxicity phenomena in the production of tissue cultures, and the productivity level, which is often very low (Collin, 2001).

Hence, the easiest and quickest way to obtain essential oils so far is the specialized cultivation of starting plant material. Many of the essential oils traded worldwide are obtained from plants that are native to Mediterranean environments (Fig. 1), and their wide trade opens new crop opportunities to farmers with arable land. At this point, a question immediately arises, and it relates to the choice of the plant-growing method. An overview of the world trade situation for spices, medicinal plant extracts, and essential oils (ITC, 2006), allows the observation that nowadays, and differently from the past, much attention is paid to organic production methods. This is even in the flavor and fragrance industries, which traditionally did not care about production methods, being generally more interested in obtaining a constant qualitative level of used raw material. In fact, some manufacturers have started setting special organic production lines (ITC, 2006a). The implications of such a tendency are many for crops strictly connected to the “organic” and “natural” market sector. Many European buyers, for example, tend to associate the production of herbs and related items to an idea of “naturality”, and expressly require the herbs to be cultivated with organic methods in the belief that such methods confer to the products a higher healthiness value. When their “naturality” features are enhanced by means of organic labeling, it is possible for essential oil crops to meet the requests of more cautious and exacting consumers who are willing to pay more for a “natural” and “healthy” product (Bianco and Santoprete, 1996; Thomas and Dorko, 2006).

It is still debatable whether natural products are safer than other products. Although it is certain, for example, that pesticide residues in herbs may harm the consumer, it is still uncertain whether the use of chemicals may influence other traits, such as the essential oil composition. Some preliminary studies performed in such a direction on coriander oil composition (Carrubba et al., 2002) and peppermint oil yield (Gruszczyk, 2004) did not stress any difference between materials obtained with organic or conventional production methods, but of course this topic requires further experimentation. Until now, it was only possible to conclude that the higher prices that consumers are willing to pay for a certified organic product should compensate the higher production costs linked to organic management (Pank, 1993). In our case, it is true that many essential oil crops are suitable for cultivation with a reduced use of energy and technological inputs (Demarco et al., 1999), and the growing trend in Mediterranean cropping systems towards organic production techniques offers many new possibilities for such crops.

2 Essential Oil Crops and Development Strategies for Marginal Mediterranean Lands

Many definitions of "marginality" have been suggested (Gurung and Kollmair, 2005). According to that offered by the FAO Consultative Group on International Agricultural Research (FAO-CGIAR, 1999), "marginal lands" are those "having limitations which in aggregate are severe for sustained application of a given use". In such lands, increased inputs are required to maintain productivity, and without them, options for diversification are often limited. Because of their special configuration, marginal lands cannot be cultivated like other lands, simply because their resources cannot sustain the weight of ordinarily managed agriculture. Hence, it is necessary to find some agroecosystem able to guarantee the optimization of the use of resources and their correct maintenance over time, under the assumption of the maximum economy of off-farm inputs.

For a number of reasons, many Mediterranean lands, including large areas in the inner part of Sicily, cope with severe conditions of marginality, sometimes leading to the interruption of all agricultural activities and to the abandonment of the land. Some of these constraints are linked to special environmental features of the area that may be characterized, as an example, by extreme levels of temperature and/or moisture, pedological anomalies regarding soil depth, pH level, texture, salinity, toxic substances, and orography. Some Authors (Olesen and Bindi, 2002; Thomas et al., 2004) call attention on that a further worsening of these environmental constraints would be expected in future due to global climate warming. This could bring as direct consequences habitat losses and environment unsuitability for many species, starting from those areas having a higher fragility level. Such issues are expected to have a strong impact on agronomical practices, as e.g. the choice of genotypes to be included in cropping systems (Ventrella et al., 2007). A search in the literature offers many examples of essential oil crops finding suitable cropping conditions even under such special environmental conditions as drought (thyme, oregano, and milk thistle), extreme pH soil conditions (chamomile > 9.2 and Erica spp. < 4.0), or very high soil salinity levels (chamomile and liquorice) (Fig. 2). A few essential oil crops (vetiver, rosemary, and thyme) have even been successfully used to consolidate soils at risk of erosion (Bagarello et al., 2004; Durán Zuazo et al., 2004).

Fig. 2 Many essential oil crops may grow and produce under erratic climatic conditions. In the photo: sage (*Salvia officinalis* L.) and rosemary (*Rosmarinus officinalis* L.) after a rare snowfall in western Sicily. (*Photo: A. Carrubba*)

The features above allow to suggest the introduction of selected essential oil crops in marginal farming systems as a proper and sustainable exploitation strategy (Carrubba and Catalano, 2007). Moreover, looking at the overall question from a wider point of view, some further remark is possible. The key concepts of the leading strategies used for the sustainable development of marginal lands are basically two: integration and diversification. First, all the intervention methods feasible for the development and exploitation of environmental resources of rural lands, especially when “marginal”, must pay great attention to the integration of economic development, social development, and environmental protection as “interdependent and mutually reinforcing pillars of sustainable development” (UN, 2002). One of the main goals is to promote all economical activities that fit in unitary production pathways, as well as the production of raw material, including the first transformation, and, whenever possible, the packaging and marketing processes. A tighter linkage between production, transformation, and services for distribution and marketing of the products themselves is encouraged.

Second, the aspect of economic diversification of such areas must be considered. In a context in which the small and medium concerns are mostly represented by family farms, and very often the production relies on one cash crop with a secure albeit low market income, diversification could reduce the risks linked to agricultural practice. This seems to be one of the most concrete and quickest ways practicable for farmers to enhance their income level. Economic diversification, in this context, takes two different forms: diversification of crops and enhancement of the multifunctional role of agriculture. Crop diversification is considered the integration of new species, varieties, and gene pools inside existing agricultural systems, and, in such a sense, it is also encouraged as a useful way to promote biodiversity (COM, 2006; SAN, 2004). The aspect of multifunctional agriculture, on its turn, recalls the new role that is today assigned to agriculture, which is also the satisfaction of different needs, not only from the agricultural community, but also from society as a whole. According to its new role, besides ensuring food and fiber production, agriculture should also contribute to environmental safeguards, to the supply of recreational services, to the creation of alternative opportunities for income and employment for the farmers, etc.

Do essential oil crops fit into such a framework? An answer must first take into consideration the basic property of these crops, that is, their aptitude to be transformed. Interest in crops having good industrial potential, capable of producing valuable chemicals to address most industrial sectors' needs, known as "botanochemicals" (Buchanan et al., 1980) – a term that did not receive the diffusion and spread it deserved – is growing worldwide. Although essential oil crops are mostly used for the direct seasoning of foods, a major interest is nowadays coming from their potential as raw material for the production of food flavorings, additives, or industrial raw materials. This entails a higher degree of transformation (and therefore a higher market price) compared with fresh herbs. The use of low-cost on-farm equipment could help farmers increase their income by retaining on-farm the added value of the transformation process, developing in this way small, local, agrofood industries. Interest in this area has already been seen in the USA (Quinn et al., 1998), the West Asian and North African drylands (Amri et al., 2006), and in Europe (Cristóbal et al., 2005). Here, many "minor", "alternative", or "uncommon" crops, including essential oil crops, have been suggested to small farmers seeking to diversify their income source.

Furthermore, they represent a good opportunity for agrotourist concerns, helping to attract people from urban areas by means of the development of herb-based commercial items (handicrafts, oils, extracts, and honey) (Fig. 3) besides representing a further source of aesthetic land valorization (Deidda and Mulas, 2004; Devecchi,

Fig. 3 Coriander (*Coriandrum sativum* L.), being greatly attractive to insects, has a potential as a significant honey plant. (*Photo: R. la Torre*)

Fig. 4 The esthetic value of many essential oil crops may play a role in rehabilitative or healing gardens. In the photo: Clary sage (*Salvia sclarea* L.) at full bloom. (*Photo: A. Carrubba*)

2006; Domizi et al., 2006). It is worth noting that many essential oil crops, due to their special sensory attractiveness, are listed among the species to be utilized in rehabilitative or healing gardens suggested in the therapeutic programs of the newest "horticultural therapy" (Cooper Marcus and Barnes, 1999; Ferrini, 2003) (Fig. 4).

Of course, the first thing is to improve the economic value of the crops by maximizing their yield and reducing the cost of production. Regarding the first goal, research data show that it is not difficult, nowadays, to obtain good yields from many herbs. In Mediterranean environments, especially when marginal, special attention must be paid to the choice of the species to cultivate and on the cropping technique to apply; however, many such possibilities are available to farmers. Table 1 shows some examples of essential oil crops that could prove useful as crop species in Mediterranean marginal environments.

Some problems arise when the economic feasibility of production processes is considered. Most cropping techniques traditionally used for essential oil crops rely heavily on manpower. Because underdeveloped countries mostly have low labor costs, it is difficult for developed countries to compete because of their relatively

Table 1 Products, active ingredients, and chemotypes identified by literature of some selected essential oil crops grown in Mediterranean areas, according to botanical family

Plant	Utilized part	E.O. content (%)	Main active ingredients of E.O.	Identified chemotypes	References
Apiaceae (ex Umbelliferae)					
Anise (*Pimpinella anisum* L.)	Fruits ("seeds")	1.5–5	Trans-anethole (80–95%), methyl chavicol, anis aldehyde.		Babulka (2004); Santos et al. (1998)
Caraway (*Carum carvi* L.)	Fruits ("Seeds")	1.0–9.0	Carvone (45–62%), limonene (35–50%)		Lawrence (1996); Sedláková et al. (2003) and (2003a).
Coriander (*Coriandrum sativum* L.)	Fruits ("Seeds")	0.5–2.5	Linalool (60–70%)		Carrubba et al. (2002); Diederichsen (1996)
Cumin (*Cuminum cyminum* L.)	Fruits ("seeds")	2.1–2.7	γ-terpinene (11.4–18.5%), p-cymene (8.8–14.7%), cumin aldehyde (25.1–34.4%)		Bandoni et al. (1991)
Dill (*Anethum graveolens* L.)	Fruits ("Seeds), herb	2.3–3.5	Carvone (40–60%)	(i) limonene 40–51%, carvone 44–58%; (ii) limonene 31–41%, carvone 25–47%, dillapiole 6–32%; (iii) limonene 37–47%, carvone 18–46%, myristicin 0.2–20%, dillapiole 6–32%	Lawrence (1994); Simon (1993)

Table 1 (continued)

Plant	Utilized part	E.O. content (%)	Main active ingredients of E.O.	Identified chemotypes	References
Fennel (*Foeniculum vulgare* Mill.)	Seed, herb[1]	1–6	Anethole Fenchone (bitter fennel only)	(i) anethole >60% a) anethole >66.5%, estragole < 7%; b) anethole >63.5%, estragole 12.5–15%; c) anethole >60%, estragole <7% d) anethole >62%, estragole 8–15%, fenchone 16–25%; (ii) fenchone >30%; (iii) estragole >30%.	Bernath et al. (1996); Carrubba et al. (2005)
Asteraceae (ex Compositae)					
German chamomile (*Chamomilla recutita* (L.) Rausch.)	Flowers	0.2–0.4	α- and β-bisabolol, bisabololoxyde A and B, (pro)chamazulene.	(i) > bisabololoxyde A (chem. "A") (ii) > bisabololoxyde B (chem. "B") (iii) > α–bisabolol (chem. "C")	Franz (1992); Dellacecca (1996a)
French tarragon (*Artemisia dracunculus* L.)	Leaves, herb.	0.3–3.0	methyl chavicol (70–80%), anethol (10%), trans-β-ocimene (up to 22%), cis-β-ocimene (up to 15%), γ-terpineol (up to 17%), limonene (2–6%).		Arabhosseini et al. (2007); Bruneton (1995); Catizone et al. (1986)

Table 1 (continued)

Plant	Utilized part	E.O. content (%)	Main active ingredients of E.O.	Identified chemotypes	References
Lamiaceae (ex Labiatae)					
Basil (*Ocimum basilicum* L.)	Leaves	0.04–0.7	Linalool (15–60%), methyl chavicol (0–37%), eugenol (4–40%), 1,8-cineol (1–17%), cynnamic acid, anethole.	(i) linalool; (ii) methyl chavicol; (iii) both linalool and methyl chavicol; (iv) both linalool and eugenol; (v) both methyl chavicol and methyl eugenol.	Ceruti et al. (1993); Elementi et al. (2006); Grayer et al. (1996); Marotti et al. (1996); Sifola and Barberi (2006); Simon et al. (1990)
Calamintha (*Calamintha nepeta* subsp. *nepeta* (N), *C. nepeta* subsp. *glandulosa* (G)	Leaves, inflorescence	0.4–1.2	Pulegone, menthone, piperitone, piperitone oxide.	(i) high menthone (>40%); pulegone 19%, piperitone oxide *trans* 8%, limonene 5%. piperitenone oxide <1%; (ii) high piperitone oxide *trans*(≅ 30%); limonene 13%, piperitenone oxide 12–13%, menthone 9%, pulegone 12%; (iii) high pulegone (≅ 50–56%); menthone 20%, limonene 6%, piperitone oxide *trans*1%; piperitenone oxide <1%, .	Ristorcelli et al. (1996); Baldovini et al. (2000)
Clary sage (*Salvia sclarea* L.)	Leaves, inflorescence	0.19–0.52	Linalool (15–70%) linalyl acetate (14–77%)		Carrubba et al. (2002a)
Hyssop (*Hyssopus officinalis* L.)	Flower heads	0.3–0.9	α-pinene (50%)		Ceruti et al. (1993)

Table 1 (continued)

Plant	Utilized part	E.O. content (%)	Main active ingredients of E.O.	Identified chemotypes	References
Lavender and hybrids (*Lavandula* spp.)	Leaves, inflorescence	1.4–1.6	In *L. vera* DC: linalool (25–38%), linalyl acetate (25–45%), cineole (0.3–1.5%, camphor (0.2–0.5%). In *L. spica* auct.non L.: linalool (25–50%), linalyl acetate (< 3%), cineole (30–40%, camphor (8–20%) In *L. x intermedia* Emeric ex Loisiel: linalyl acetate (28–38%), cineole (4–7%, camphor (6–8%).	(i) linalool >30%; (ii) linalyl-acetate >30%; (iii) lavandulyl-acetate >25%	Bruneton (1995); Ceruti et al. (1993); Tucker et al. (1984)
Lemon balm (*Melissa officinalis* L.)	Leaves	0.05–0.2	Neral, geranial, germacrene-D		Ceruti et al. (1993)
Mint (*Mentha* spp.)	Herb, leaves	In *M. x piperita* L. var. *citrata* 1.2–1.4 on the whole plant, 2.5–2.8 on leaves.	Carvone, menthol, menthyl acetate, pulegone, linalool, linalyl acetate, 1,8-cineole	in *M. x piperita* L. var. *citrata* (Ehrh.) Briq.: (i) >linalool, <linalyl-acetate; (ii) >linalyl-acetate, <linalool in *M. pulegium* L.: (i) pulegone; (ii) pulegone-menthol; (iii) carvone-pulegone.	Ben Fadhel et al. (2006); Bruneton (1995); Diaz-Maroto et al. (2003); Malizia et al. (1996); Simon (1993); Paris et al. (1974)

Table 1 (continued)

Plant	Utilized part	E.O. content (%)	Main active ingredients of E.O.	Identified chemotypes	References
Oregano (*Origanum* sp.)	Inflorescence	0.5–4.0	Thymole Carvacrole	(i) high thymole; (ii) high carvacrole	De Mastro et al. (2004); Melegari et al. (1995)
Rosemary (*Rosmarinus officinale* L.)	Leaves, inflorescence	1.5–3.5	α–pinene, camphor, 1,8-cineole, borneol, bornyl acetate, verbenone	(i) cineoliferum (high 1,8-cineole); (ii) camphoriferum (camphor >20%); (iii) verbenoniferum (verbenone >15%).	Angioni et al. (2004); Carrubba et al. (2006a); Ceruti et al. (1993); Cioni et al. (2006); De Mastro et al. (2004a)
Sage (*Salvia officinale* L.)	Leaves, inflorescence	0.3–0.6	α– and β–thujone, 1,8-cineole, eucalyptol, linalyl acetate	*α- thujone/β- thujone ratio:* (i) 10:1 α/β, (ii) 1.5:1 α/β, (iii) 1:10 α/β.	Ceruti et al. (1993); Dudai et al. (1999); Perry et al. (1999)
Savory (winter) (*Satureja montana* L.) Savory (summer) (*S. hortensis* L.)	Inflorescence	0.5–1.0	Carvacrole Thymole	In *S. montana*: (i) high thymole (ii) high carvacrole	Bruneton (1995)
Thyme (*Thymus vulgaris* L.; *Thymus capitatus* (L.) Hoffm. & Link = *Thymbra capitata* L. (Cav.))	Leaves, inflorescence	0.5–1.5	Carvacrole Thymole	According to the prevailing occurrence of: (i) thymole (ii) carvacrole (iii) geraniol (iv) linalool (v) α-terpineol (vi) *trans*-4-thujanol and *cis*-8-myrcenol (vii) cineol	Bruneton (1995); Catizone et al. (1986); Granger and Passet (1973); Rodrigues et al. (2006)
Rosaceae					
Rose (*Rosa damascena* L., *R. centifolia, R. Gallica*)	Flowers	0.03–0.04	(-)-β-citronellol (38%), geraniol (14%), nerol (7%), eugenol (1%)		Retamar (1993)

[1] Only used for domestic purposes.

higher labor costs. For this reason, intensive cultivation with irrigation, adoption of improved varieties, and more effective cropping techniques and postharvest technologies (including better methods of dehydration) could lead to improvements in the productivity of such crops and also minimize the cost of production processes.

Another important concern, especially when the products are expected to be used for industrial transformation, is improving their quality. It is likely that in the near future, greater market penetration will be achieved by selling a higher-quality product, with control of microflora contamination, an improved shelf life, a guaranteed level of active ingredients, and produced according to set guidelines (with few or no pesticides). Growing such crops with organic cropping techniques (governed by the EU) that may offer a substantial safety guarantee to buyers and consumers is an important opportunity for farmers.

3 Essential Oil Production in Plants

In plants, essential oils are generally recognized as secondary metabolites. Chemically, their primary components are terpenes (mono- and sesquiterpenes, and to a lesser extent diterpenes) and aromatic polypropanoids, synthesized via the shikimate and mevalonate pathways (Croteau et al., 1986; Lamarti et al., 1994; Sangwan et al., 2001; Simon, 1990). The shikimate pathway intermediates and aromatic amino acids are precursors of a large number of secondary plant products (Herrmann, 1995; Kutchan, 1995). Each essential oil generally retains the organoleptic characters (taste and flavor) of the parent plant, and the special and unique aroma pattern of each plant species is provided by the characteristic blending of its aromatic components. This explains the huge number of fragrances that are available in nature and the fact that, in practice, industry considers each a whole raw material rather than a mixture of different chemical principles (Salvatore and Tateo, 1992).

Minimal variations in the ratio among components may generate important modifications in the aromatic profile of the essential oil. These are sometimes too small to be instrumentally detected, but large enough to be perceived by human senses. Many techniques have been developed to characterize the essential oils obtained from plants, and much effort has been devoted to studying their biological activities. Being secondary plant metabolites, their production in plants could vary with the environment (Sangwan et al., 2001; Bruni, 1999) and with the ability of the plants to allocate their resources. For example, crops that produce mainly primary metabolites would have high seed yields in favorable environments, and crops that produce high quantities of secondary metabolites would have high essential oil yields in unfavorable environments (de la Fuente et al., 2003). A further complication is the existing dynamic relationships between primary and secondary plant metabolism, where when there is a demand, the secondary compounds may be recycled back into primary metabolites (Collin, 2001).

Considerable research has been undertaken into essential oil production in plants, utilizing a large number of plants and many different technical and scientific approaches. Attention has also been paid to the simultaneous formation of different compounds within the plants that might affect the results of this research. Bouwmeester et al. (1995) argued that the formation of carbohydrates in seeds would result in an apparent increase of essential oils, even if essential oil formation itself has not been affected. The authors suggested that to avoid confusion, the absolute amount of essential oil in each seed should be referred to. However, the available literature indicates that the classical volume/weight percentage is by far the most often used method worldwide.

Essential oils are produced by plants for many reasons, including the attraction of pollinating insects (Lodi, 1986), repelling noxious insects by means of toxic, repellant, and antifeedant activities (Van Beek and de Groot, 1986; Simmonds, 1997; Bottega and Corsi, 2000), improving plant disease resistance (Goidanich, 1981), allelopathic effects that could be involved in interspecific competition mechanisms (Raven et al., 1979), or increasing drought resistance in semi-arid environments (Fluck, 1955; Munné-Bosch and Alegre, 2001). They are produced and stored in specialized plant structures that are distributed over the plant's entire epidermis or in special organs. These include the sacs or ducts of the epidermis in citrus peels or *Eucalyptus* leaves, or the glands and glandular trichomes originating from epidermal cells in *Labiatae* (D'Andrea, 2006; D'Andrea and Circella, 2006; Maleci Bini and Giuliani, 2006; Sangwan et al., 2001; Weiss, 1997) (Fig. 5).

Essential oils are processed from plants using distillation or extraction. Steam distillation is the most common method used by commercial-scale producers, and uses heat from steam or water to break the oil glands in plants and vaporize the oil, which is then condensed and separated from the wastewater. Distillation can be undertaken using on-site facilities, mobile units that come to the farm, or on-farm equipment that requires a significant, but not impossible, capital investment. Sometimes the waste, which retains many of the organoleptic traits of the herb, finds some market opportunity. For example, the wastewater from oregano distillation is

Fig. 5 *Thymus longicaulis* Presl. In evidence the essential oil glands in leaves. (*Photo: R. Bontempo*)

usually sold in Turkey as “Kekik suyu”, which is claimed to have positive digestive effects. The possibility has also been suggested that distillation wastewaters could be submitted to a further extraction process to recover a greater amount of essential oil (Rajeswara Rao et al., 2005). Several new processing facilities for oil extraction have been reported in the literature. For example, supercritical carbon dioxide, microwave-assisted hydrodistillation, or novel solvent extraction techniques (Joy et al., 2001; Kosar et al., 2005; Platin et al., 1994; Riela et al., 2008; Sedláková et al., 2003) have been suggested, but in many cases their costs are prohibitive for on-farm realization.

4 Cultivation of Essential Oil Crops: Goals and Constraints

In order to improve the economic competitiveness of essential oil crops, the first important step is to state the goals for such cultivation. There is a considerable difference between cultivation for producing herbs, essential oils, or secondary metabolites dealing with some biological activity. Generally speaking, these may be thought of as subsequent steps, with each product representing the raw material for the following industrial pathways. Consequently, the income level that may be obtained from passing one type of product to the following processing step will vary (Carrubba et al., 2006c). As an example, dried rosemary is a commercial herb *per se*, but it may also be considered the starting material for the production of an essential oil, which may further represent the raw material for the extraction of some active principles dealing with antioxidant properties. Each single step:

(1) requires a higher technical refinement than the preceding one,
(2) confers to the obtained product a higher degree of economic value, and
(3) possesses very specific quality standards to which each product must conform.

Usually, the income derived from producing the raw material for one step varies from that of another. This is because of the different levels of expertise required when shifting from an agricultural to a more industrial process. Retaining as many production steps as possible on-farm would enable farmers to obtain higher added value, which could prove a great advantage.

The first economic interest in essential oils is oriented towards the industrial exploitation of their naturally occurring actions, that is, the activity due to their aromatic, insecticidal, antioxidant, and antimicrobial compounds. These would be mostly used as natural products in food, cosmetics manufacturing, and preservation. In fact, many papers have been published worldwide regarding the numerous properties of essential oils. For example, in 2003, Kalemba and Kunicka estimated that more than 500 works had been published just concerning their antimicrobial activity. It is likely that this number has now been greatly surpassed.

The scientific finding that an essential oil possesses some specific activity (antimicrobial, antioxidant, etc.) does not represent per sea certainty of its suitability to industrial use. In order to find a suitable use, every plant extract must retain very specific characteristics, roughly summarized by the triple constraint "quality–security–effectiveness" (Franz, 1996), i.e., it is necessary that the products derived from it must fulfill adequate and constant quality standards, address consumers' concerns regarding the safety of their use, and be satisfactorily effective. Regarding the last requirement, some concern is related to the amount that needs to be added to the various industrial items to show a good effectiveness of use. As an example, when essential oils are intended as antioxidants for food manufacturing, in order to have a satisfactory effectiveness they must be added to foodstuffs in very large amounts. This inevitably leads to a modification of the taste and flavor of the products to which they are added. For this reason, they may only be added to a limited number of suitable food items (Roller, 1995; Brul and Coote, 1999). In cases in which the typical scent of a given herb is unpleasant, a recent possibility is offered by deodorized extracts, endowed with technical properties identical to those of the starting plant material, but absolutely free from its typical odor. As an example, starting from rosemary extracts, some antioxidant mixtures have already been patented, produced, and sold, such as GUARDIAN^{TM} (Danisco Co. Ltd., Denmark) (Fig. 6).

Fig. 6 Rosemary (*Rosmarinus officinalis* L.) has been largely studied for its antioxidant properties. (*Photo: A. Carrubba*)

5 Factors Affecting Essential Oils Yield and Composition

Because the first goal of cultivating essential oil crops, whatever their final use, is to obtain adequate amounts of plant material, biomass productivity is obviously the first target. Many studies have been performed around the world to improve various aspects of productivity of essential oil crops and the role of agronomic practices on yield (Pank, 1993; Carrubba et al., 2006; 2006c). It must be considered, however, that when quality aspects are concerned, conclusions may be dramatically different from those concerning bare quantitative aspects. In some cases, the same factors positively affecting the biomass yield of one herb might exert a negative action on its quality features. This is the reason why a decision about the goal of cultivation should be taken as the first priority. In so doing, the same species could be cultivated according to different cropping protocols that would depend on the kind of product to be obtained.

Many factors are claimed to exert an influence on the yield and chemical composition of essential oils. Generally, these factors are classed as "endogenous" and "exogenous". The first group includes all characteristics natural to the plant, such as its genetic constitution, but also other nongenetic factors such as its age or development stage. The second group includes all external factors that plants may experience during their growth cycles (Bruni, 1999). Both groups have extremely variable effects on essential oil quantity and quality. First, it has been ascertained that certain essential oil components are more sensitive than others to variations in plant characteristics and environmental conditions. This is the case with some terpenic compounds such as α-pinene, p-cimene, α-terpinene, and linalool in coriander (Carrubba et al., 2002), or α-thujene, α-terpinene, β-phellandrene, and camphor in fennel (Carrubba et al., 2005). These were of the greatest importance in the assessment of the variability of essential oil composition, whatever its source (geographic provenance, crop management, and age of the samples).

5.1 Endogenous Factors: The "Inner" Sources of Variability

Because the essential oil composition is governed by the biosynthetic pathways (which are under enzymatic control) that act in plant metabolism, it is undoubtedly genetically determined. Studies performed on the heritability of qualitative essential oil traits have ascertained that the biosynthesis of certain compounds (such as prochamazulene or bisaboloids in chamomile) underlies a simple Mendelian behavior (Franz, 1992). The studies found that an "aut/aut" law applies (they may or may not be there) and allowed the deduction that the compounds are determined by only one (or few) gene(s). Other compounds are, instead, under polygenic control, and the continuous conversion from one compound to another (such as the shifts among the various bisaboloid forms in chamomile) may explain the occurrence of intermediate chemotypes dealing with different amounts of the above compounds (Franz, 1992; Wagner et al., 2005). On this genetic basis, however, all the other factors play

Fig. 7 Many essential oil crops reach their maximum essential oil content at flowering time. In the photo: Oregano (*Origanum vulgare* L. ssp. *hirtum* (Link) Ietswaart) at full blooming. (*Photo: A. Carrubba*)

some role, and a great deal of experimental work has been carried out on this subject. Concerning the nongenetic endogenous factors, it is generally acknowledged that most aromatic plants gain their maximum levels both in yield and in the quality of their essential oils when they are close to the blooming stage (sometimes at the beginning, sometimes at the end) (Fig. 7). A higher essential oil content near flowering was noted for oregano (Ietswaart, 1980; Putievsky et al., 1988), peppermint (Dellacecca, 1996), *Artemisia annua* (Chalchat et al., 1994), *Thymbra spicata* (Müller-Riebau et al., 1997), *Thymbra capitata* (Rodrigues et al., 2006), and *Ocimum basilicum* (Macchia et al., 2006). In some cases, it was also confirmed when the commercial product was formed by parts of the plants other than the flowers (Shultz and Stahl-Biskup, 1991). This general feature is not always so definite, and a different tendency was observed in *Salvia officinalis*, in which oil obtained from shoots collected in May (i.e., at flowering) was 1.6 mL kg^{-1}, much less than the 4.7 mL kg^{-1} achieved when harvested in September (Scartezzini et al., 2006). Similarly, in clary sage (*Salvia sclarea* L.) an increase in the essential oil content of inflorescences was found when they were passing from the full blooming stage to the seed ripening stage (Carrubba et al., 2002b). In trials carried out on basil, maximum oil yield was obtained at the 50% seed set stage (Sangwan et al., 2001).

Ontogenetic development may also influence the biosynthetic pathways of oil constituents (Piccaglia et al., 1991), and therefore their relative quantities in the essential oils. In peppermint (*Mentha* × *piperita* L.), the (-)-menthone content was found to decrease and (-)-menthol content was found to increase during the vegetative cycle (Bruneton, 1995). *Thymbra spicata* showed an increase in the concentration of phenols, especially carvacrol, from spring to mid-summer (June–July), when the plants had reached full blooming (Müller-Riebau et al., 1997). In clary sage, moving from full blooming to seed ripening resulted in a significant increase

Fig. 8 In sage (*Salvia officinalis* L.), the essential oil obtained from younger leaves has a different composition with respect to older leaves. (*Photo: A. Carrubba*)

in some important oil compounds, e.g., linalyl acetate, which was found to vary from 35% to 53% (Carrubba et al., 2002b). In common sage (*Salvia officinalis* L.), a delay in the collection of shoots from May to September resulted in a decrease of α- and β-thujone and camphor in the oil, and therefore to an improvement in oil quality (Scartezzini et al., 2006). Significant variations in essential oil components with the growth stages of plants were also assessed in leaves of both *Ocimum basilicum* (Macchia et al., 2006) and *Coriandrum sativum* (Smallfield et al., 1994).

Irrespective of development stage, in perennials, the age of the plant seems to play some role as well: oils extracted from *Lavandula spica* Vill. (Carrasco, 1980) and peppermint (Dellacecca, 1996; Gruszczyk, 2004; Piccaglia et al., 1993) have shown important variations both in yield and composition from one year to the next. Probably due to a similar mechanism, several trials on sage found significant differences between oil yield and composition in lower (older) leaves compared with upper (younger) leaves (Bezzi et al., 1992; Dudai et al., 1999) (Fig. 8).

5.2 Exogenous Factors: Variability Due to the Environment

The second group of factors ("exogenous") includes all growing and environmental conditions (e.g., temperature, daylength, quality of light, soil and air moisture, wind patterns, and nutrient levels) that may exert some direct or indirect influence on essential oil production and accumulation in plants. Such an effect may be more or less intense, e.g., being more important in species having a more superficial location of oil storage structures, such as the glandular trichomes in *Labiatae* (Bruneton, 1995). Studies regarding the effect of climate on yield and composition of secondary metabolites are many, and have often led to interesting results. For example, the common belief that aromatic plants possess a stronger aroma when grown under arid and sunny climates seems to find a scientific basis from the demonstrated increased activity of the phenylalanine ammonia lyase (PAL) enzyme under these prevailing climatic conditions. This is because PAL causes protein synthesis to shift towards the production of phenols, which are the major compounds responsible for the aromatic features of essential oils (Landi, 1994). A relationship between various climatic indexes and the occurrence of certain chemotypes was noted for *Thymus piperella* L. (Boira and Blanquer, 1998).

However, if studies concerning climatic conditions as a whole are interesting in the assessment of the distribution of a certain genotype, great scientific interest is linked to ascertaining the environmental trait responsible for a given action on essential oil biosynthesis. This is quite a difficult task, especially in Mediterranean areas where chemical polymorphism is important (Boira and Blanquer, 1998) and its relation with environmental factors is the subject of a deep debate.

Temperature surely plays a crucial role, and since all secondary metabolites are the result of a series of biochemical steps, each with its own optimal temperature, it is possible that the best temperature for obtaining a specific compound is the one resulting from the optimal temperature levels for the single reactions (Catizone et al., 1986). High (but not excessive) temperatures are considered, as a whole, to be best for producing essential oils, a result validated by much experimental data on *Pelargonium* spp. (Motsa et al., 2006) and chamomile (Bettray and Vömel, 1992). The composition of essential oils in relation to temperature has been studied as well, and, for example, in chamomile, the (-) α-bisabolol, pro-chamazulene, and apigenin content in flowers increased significantly when the temperatures were raised from 16 °C to 20 °C to 26°C (Bettray and Vömel, 1992) (Fig. 9).

Because secondary metabolites are a side effect of photosynthetic activity, it may be expected that variations in light duration, intensity, and quality can affect their production in plants. Generally speaking, plants growing under good illumination

Fig. 9 In essential oil from Chamomile (*Chamomilla recutita* Rausch.) some compounds show an increase with temperature. (*Photo: A. Carrubba*)

exhibit an increase in oil yield with respect to the same plants grown in shade. This feature was demonstrated in *Pelargonium*, both in whole plants (Kaul et al., 1997) and in tissue cultures (Brown and Charlwood, 1986), where the oil obtained from tissue cultures of *Pelargonium fragrans* exhibited 50% limonene in dark-grown tissue cultures compared with 5% limonene in the oil extracted from the parent plants. A general biochemical explanation of the higher amount of esters (highly aromatic substances) in plants grown in sunny areas suggests that the photolysis reaction, by eliminating the water molecules obtained from the esterification processes inside plants, would stabilize esters in the plants themselves (Catizone et al., 1986). Photoperiod was also noted as a crucial factor in oil production and composition, and a long photoperiodic treatment was responsible for an increased amount of *cis*-sabinene hydrate in marjoram oil (Circella et al., 1995) and higher menthol content in some mint species (Fahlén et al., 1997), probably due to a favored conversion of menthone to menthol in the leaves (Voirin et al., 1990).

The effect of light quality was taken into account by Maffei et al. (1999), whose data demonstrate that UV-A radiation on peppermint during the day generates an increase in total leaf area and total essential oil content, menthofuran, and menthol.

Many other examples could be considered to demonstrate the importance of environmental factors in assessing (alone, in interactions with themselves, or in genotypic interactions) the various quality aspects of essential oil crops. It is not incorrect to note that cropping techniques are also an important source of variation in the growth of plants, and that a difference in crop management may therefore generate important variations in plant biochemistry and quality.

6 Breeding Activity

Research into the breeding and genetic improvement of essential oil crops has been sparser than the efforts expended on other crops such as cereals, and much work remains to be done: genetic variability in essential oil crops is considerable and scarcely explored, and a great possibility exists to use this variability for future breeding programs. Notwithstanding, the literature shows many examples of screening, selection, and breeding processes of essential oil crops, utilizing various techniques ranging from traditional crossing and selection methods (Dudai et al., 1999; Landi, 1994; Landi and Bertone, 1996) to the most advanced biotechnology programs (Shetty et al., 1996; Novak, 2006).

Efforts into breeding essential oil crops may take one of two different approaches (sometimes both): genetic improvement for crude yield and genetic improvement for one, or more, selected qualitative features. In many cases, unfortunately, it seems that most of the results of breeding and selection efforts are still unavailable to farmers; very few essential oil crops may show satisfactory availability of certified reproduction material, and most are cultivated using locally grown ecotypes, devoting little interest to the choice of the best genotype (Fig. 10).

Fig. 10 Few essential oil crops have a satisfactory number of commercially available improved varieties. (*Photo: A. Carrubba*)

6.1 Breeding for Biomass Yield

The approach oriented to the obtainment of high crude yield involves selection for enhancing the biomass yield of a certain plant, or its marketable part (seeds, roots, or flowers). That means, the plant’s growth mechanisms should be pushed to the highest efficiency in exploiting environmental resources. Some authors (McConnell and Anderson, 2002) call attention to the generally low environmental plasticity of some of the crops above, in that behaving as “weedy” species does not enable them to succeed in exploiting environmental resources, and they improve performance under low fertility conditions. This is the case for some species grown for fruit ("seed"), such as coriander and dill, where higher fertility conditions push towards an enhancement of biomass production, consequently reducing seed yield.

It is likely that much work remains to be done to develop genotypes more capable of "capitalizing" on environmental resources, and therefore to react more positively to technical inputs such as fertilization.

In fact, many of the most common essential oil crops bear morphobiological traits originating from their adaptation to growing in the wild, and that retaining such traits often sets limits to their agronomic suitability. Breeding was, therefore, also addressed to solve some agronomic problems that may arise in cultivation, such as seed dormancy, indeterminate growth habit, or lodging tendency (Holm and Slinkard, 2002; Langbehn et al., 2002). Seed dormancy may be an important concern when planning and managing sowing operations, and strategies to cope with this inconvenience may vary depending on whether it is caused by physical (such as thickness or special traits of the outer seed layer, which is easily fixed by seed scarification) or physiological mechanisms. A few studies have been oriented towards the study of the mechanisms underlying seed germination, and, although information is far from complete, some interesting conclusions may be drawn. For example, it has been ascertained that in some species, especially those bearing small seeds, the germination process is tightly dependent upon light, showing a strong inverse correlation with the depth of planting (Benvenuti et al., 2006). In other studies, the use of hormones such as gibberellic acid has shown good effects on breaking dormancy in seeds of *Lavandula angustifolia* Mill. (Macchia et al., 1996).

An indeterminate growth habit is considered an important adaptive trait to extend the reproductive period and ensure reproductive success for plants in environments in which the availability of water in the soil is variable and unpredictable (Arnon, 1992). Similar to seed dormancy, this is a very common trait correlated to the lack of genetic amelioration in many essential oil species, especially in the *Apiaceae*,

Fig. 11 Indeterminate growth habit may be a problem in many essential oil crops. In the photo: Coriander (*Coriandrum sativum* L.) plants bearing flowers and seeds at different ripening stages. (*Photo: A. Carrubba*)

but also in other families. It is mostly considered unwelcome because the presence of reproductive organs at various stages of development in plants may be a serious constraint to the mechanization of harvest (Fig. 11).

In some species, the results of breeding activity addressed to solve these agronomical problems and enhance plants productivity have been rather satisfactory: due to the efforts of research centers, e.g. from Canada (Blade and Slinkard, 2002) and India (Kallupurackal and Ravindran, 2005), in a few annuals such as coriander, caraway, fennel, and dill, some improved material is already available. Similarly, high-yielding clones of essential oil perennial species such as rosemary, lavender, or thyme have been selected (Catizone et al., 1986; Mulas et al., 2002; Rey, 1992; Verlet, 1992). Additional efforts should be oriented to a wider diffusion of such improved genotypes.

6.2 Breeding for Qualitative Traits

Concerning breeding for essential oil yield and chemical characteristics, intense research has been conducted worldwide, and many plants have been studied to investigate the composition of their oils to detect the occurrence of valuable and stable chemotypes. Chemotypes, or “chemical breeds” (Bruneton, 1995) are groups of individuals within each species that even while bearing the same morphological structure may be distinguished according to special characteristics of their chemical traits. Studies in this direction have led to the establishment of a new discipline: the study of plant classification called chemotaxonomy (Granger and Passet, 1973; Granger et al., 1973; Weiss, 1997).

Of course, the choice of the most proper chemotype, suitable for a selected market sector or industry, could be crucial for the commercial success of the species to be cultivated. Table 1 shows some of the chemotypes found in various essential oil crops from the available literature; examples are given for thyme, oregano, and lavender, which are targeted to the many studies characterizing and exploiting their essential oils (Verlet, 1992).

Breeding activity regarding chemical oil characteristics has been primarily directed to the selection of genotypes having high quantities of special compounds with a particular economic value or considered primarily responsible for the aromatic properties of the essential oil, such as *cis*-sabinene hydrate in marjoram (Langbehn et al., 2002), and chamazulene and bisabolol in chamomile (Franz, 1992). Otherwise, it was directed towards obtaining genotypes with a low content of unwanted compounds, such as thujone in sage or elemicin in tarragon (Catizone et al., 1986). Also in this case, a further diffusion of these improved genotypes would be of great practical interest.

7 Cropping Technique and Quality Traits

Because they act to modify the growth environment of plants, cropping techniques are often crucial in assessing many quality traits of essential oil crops; a search of the literature shows a major influence of agronomic factors on their yields and essential oil composition. Hence, the choice of cropping technique must be straightforward and fit into the rotations and mechanization of the farm. However, it appears that much effort must still be applied to the development of seed selection, breeding, harvesting technology, distillation technology, and organic production.

7.1 Propagation and Planting Management

Many essential oil crops (such as hybrid peppermint) are sterile; hence, they must be propagated vegetatively by rhizomes, stolons, or plant parts. When seed propagation is possible, it could present an interesting opportunity for farmers. However, the choice of propagation method is claimed to exert a significant effect on the quality traits of many essential oil species. When the crops are open-pollinated, their seeds often produce plants that are not homogeneous for growth or aroma. Bruneton (1995) reports, as an example, significant variations in the chemical composition of essential oil obtained from lavender plants propagated by seed or vegetative multiplication, and he concludes that the second method is more suitable for cultivating plants bearing constant selected morphological, biological, and qualitative characteristics. The use of direct seeding in the field is a rather difficult practice for perennials, because, as experienced for sage (Caligani and Adamo, 1987), their generally slow establishment in the field causes many problems concerning competition with weeds (Fig. 12).

In addition, planting methods (population density, arrangement in space, time of sowing, or planting) may be crucial for obtaining the best cultivation results

Fig. 12 Emergence may be a crucial factor in the establishment of essential oil crops. In the photo: a germinating fennel (*Foeniculum vulgare* Mill.) plantlet. (*Photo: R. la Torre*)

Fig. 13 A proper settlement of rows and inter-row distances has a major importance in crop management. In the photo: 1-year-old Oregano (*Origanum vulgare* L. ssp. *hirtum* (Link) Ietswaart) at full blooming. (*Photo: M. Militello*)

(Fig. 13). Plant population is important because essential oil crops may have varying responses to increases in intraspecific competition. In sage, a higher plant density was accompanied by a lower unitary plant biomass, because of a lower number of leaves per plant and a smaller leaf size, but the higher number of plants per unit area seemed to compensate for this feature (Bezzi et al., 1992). Similarly, many species cultivated only for plant biomass (such as sage, oregano, rosemary, and thyme) seem to react positively to an enhancement of plant population provided there is a satisfactory level of water and nutrients in the soil (De Mastro et al., 2006). It is not clear, however, if such a positive response in terms of aerial biomass is accompanied or not (and if it is, to what extent) by modifications in essential oil composition. Some results regarding this may have been obtained for peppermint (Dellacecca, 1996), in which variations both in yield and content of essential oils were assessed with varying plant populations. However, in oregano, a decrease in essential oil yield with higher plant density seemed to be mostly due to a higher percentage of stems and woody parts (having a lower essential oil content) in the harvested material (Scarpa et al., 2004).

Concerning planting date, many annual essential oil species (anise, cumin, and coriander), being fairly sensitive to frost and cold, are usually sown in spring. Notwithstanding, in Mediterranean environments, in which climatic patterns are characterized by mild winter temperatures, a prevailing distribution of rainfall in autumn and winter, and severe drought periods in spring and summer, an earlier sowing date is claimed to exert a major effect on the establishment of crops. This is because it allows plants to grow when the water content in the soil is still satisfactory, i.e., before drought occurs. In any case, an earlier intervention allows, generally speaking, a higher stand uniformity and plant population, and therefore higher biomass yields (Catizone et al., 1986).

This general statement seems especially important in annual crops, since sowing date may influence the timing of harvest. This, in turn, may be very important both for quantitative and qualitative aspects of production. The advantage of an earlier sowing date, well assessed in coriander (Carrubba et al., 2006b; Luayza et al. 1996), fennel (Leto et al., 1996; Masood et al., 2004), anise (Zehtab-Salmasi et al., 2004), and cumin (Mirshekari, 2004), could be due to the progressive lengthening of the vegetative growth stages, especially those immediately preceding the onset of flowering, the duration of which has shown a high direct correlation with yield in some experiments (Carrubba et al., 2006b).

In perennials, experimental findings seem to give the same results, and under semi-arid climatic conditions, there is a substantial agreement on the necessity to make the planting date close to rainy periods, even when the crop is managed under irrigation (Rajeswara Rao, 1999). Such a choice allows a better establishment of crops, e.g., in peppermint it allowed the formation of many runners and an earlier canopy closure, which resulted in higher biomass yields when compared to a spring-planted crop (Piccaglia et al., 1993). A similar result may be found concerning essential oil yields, which clearly showed a decrease with a postponement in sowing date for peppermint (Piccaglia et al., 1993), dill (Hornok, 1980), anise (Zehtab-Salmasi et al., 2004), and cumin (Mirshekari, 2004). In coriander, sowing date seemed to have a slight influence on oil composition (Carrubba et al., 2006b).

7.2 Weed Management

This is one of the major constraints on the cultivation of essential oil crops. Weeds exert an effect as crop competitors, are responsible for problems of harvest mechanization, and when mixed with the harvested product may alter its end quality (Fig. 14). Competition with weeds, which are involved in the sharing and consequent allocation of environmental resources, may reasonably be considered a factor affecting essential oil yield and composition. In an Argentinean coriander landrace

Fig. 14 Weeds may be a major concern for essential oil crops cultivation. In the photo, a heavily infested fennel (*Foeniculum vulgare* Mill.) plot. (*Photo: A. Carrubba*)

(Gil et al., 2002), weeds were a significant factor in determining the geraniol and geranyl acetate content in the oil, but it was difficult to ascertain their real effect because it acted in interaction with location and year.

In some cases, the use of herbicides has been studied with good results. For example, the production of aromatic oils seems unaffected by herbicide application (provided the crop is tolerant to its active ingredients), and the quality of oil may even be improved (Pank, 1992; Zheljazkov and Topalov, 1992). It is true, however, that many active ingredients in herbicides have not been expressly tested on essential oil crops. Furthermore, the choice of organic production method (which, as previously stated, is often a precise choice for essential oil crop growers) sets a limit to the possibility of intervention with chemical products; in this case, the choice is restricted to a few allowed techniques. Many nonchemical solutions suitable for use under organic management have been suggested (Bond et al., 2003; Kristiansen, 2003), with results that varied according to plant species, timing of intervention, and expected results.

First, the use of transplantation instead of direct sowing may be useful for planting larger, and therefore more competitive, individuals in the field. The adoption of double instead of single rows, successfully tried for oregano (Carrubba et al., 2002a), could allow a more satisfactory execution of mechanical weed control.

Mechanical weeding is, by far, the most immediately applicable method for weed management when the use of chemicals is undesirable (Chicouene, 2007). It must be applied taking into consideration the growth stages of the crop and weeds, as well as the biology and characteristics of the weeds, but in most cases, one or two treatments are enough.

In fact, the greatest difficulty in mechanical weed control is the necessity of planning crop settlement and taking into account, from initiation, the kind of equipment used for weeding, and therefore properly setting inter-row distances. Many of the failures of mechanical weeding are linked to this lack of management.

Mulching (Fig. 15) has been successfully tried, and many growers have obtained good results using polyethylene mulch or black porous plastic (Galambosi and Szebeni-Galambosi, 1992). In cultivation trials of *Artemisia absinthium,* mulching resulted in a 5% increase in average plant weight (Giorgi et al., 2006).

Alternatively, an environmentally friendly technique is flame control, performed with special equipment that when passed over and around weeds, quickly boils the water in their cells, causing wilting of the apex and death. Flaming was tried on some essential oil crops such as coriander and fennel (Carrubba and la Torre, 2006), and sage and lavender (Martini, 1996), and the results seemed to depend upon the seasonal climatic patterns and the competition between the crop and the weeds. The low labor required represents an important advantage of flaming, but for effective weed control, an exact timing of the intervention is crucial, since flamers should be used when weeds are still young and tender. Flaming kills annual weeds completely (although more will reappear), but it does not kill the roots of perennial weeds. These will send up new shoots within a week or so after flaming; therefore, additional treatments are often required.

Fig. 15 Mulching may help in managing weeds, but the more resistant weeds may pass through the plastic film. In the photo: plastic mulch on coriander (*Coriandrum sativum* L.). (*Photo: A. Carrubba*)

7.3 Soil Nutrients and Fertilization

The nutrient level in the soil is one of the most investigated aspects of agricultural research, also including research into essential oil crops. The effect of N fertilization has been studied in detail for peppermint (Dellacecca, 1996; Piccaglia et al., 1993), sage (Bezzi et al., 1992), and marjoram (Trivino and Johnson, 2000). In general, N fertilization seems to promote plant development, but without any enhancement in essential oil. In some cases, it even seemed to negatively affect crop results, for example, allowing leaves to develop instead of other desired plant parts, delaying flowering, or interfering with the production of essential oils, such as in *Lavandula spica* (Catizone et al., 1986). An interesting hypothesis (Mirshekari, 2004) suggests that there is an inverse correlation between protein and essential oils in plants; hence, all factors that promote protein synthesis (such as N fertilization) would have a depressive effect on essential oil yield. Apparently, contrasting data come from experiments on peppermint (Piccaglia et al., 1993) and geranium (Araya et al., 2006), in which N fertilization increased not only plant biomass but also the essential oil yield per unit area. This increase could possibly be a consequence of the increased biomass level rather than an effect of the enhancement in oil percentage. In coriander, significant variations were found both in essential oil content and composition when N fertilization was enhanced from 0 kg ha^{-1} to 135 kg ha^{-1}, but the direction and amplitude of these variations were also affected by growing conditions (year and cultivation site) and genotype (Gil et al., 2002).

Much less abundant (and less conclusive) is the literature about the effects of N fertilization on essential oil quality traits. Gil et al. (2002) found that it affected the linalool content of coriander, but this was noted only in a European landrace; an Argentinean landrace was not affected at all. Piccaglia et al. (1993) found an increase in pulegone content in peppermint oil by increasing the N fertilization rate, but such an effect was detected only in one of two years.

Some interesting findings concern the effect on yield of organic N fertilization: yield enhancements have been claimed for biomass and oil in *Pelargonium* spp. (Araya et al., 2006) and in coriander seeds (Ursulino Alves et al., 2005). In both cases, the authors suggest that, besides the bare nutritional effect, some influence should be attributed to the positive action of organic fertilizers towards some soil characteristics, namely the water holding capacity, cation exchange capacity, and microbial activity.

Concerning other nutrients, there are few reference papers: generally speaking, P is claimed to have a positive influence on the development of reproductive organs and to stimulate flowering, whereas K has positive effects on root development (Radanović et al., 2004). However, to our knowledge, few experiments have been performed regarding the effect of such elements on yield and quality traits of essential oil crops. An experiment on P fertilization in peppermint (Piccaglia et al., 1993) recorded an increase in menthol content with increasing P dose, but this was only noted in one of two years. As such, no definite conclusions can be drawn.

7.4 Irrigation

Water deficiency has a major role in the growth and yield of crops, and this has been studied in depth for many plants that are native to, or cultivated in, Mediterranean environments (Fig. 16). The effects of water shortage may vary according to the duration and severity of stress, the resistance and/or tolerance features of the plant,

Fig. 16 Watering has a major effect on biomass yield, especially in dry and semi-arid climates. In the photo: sage (*Salvia officinalis* L.) under irrigation. (*Photo: A. Carrubba*)

and the plant material to be harvested (whole aerial biomass, leaves, roots, flowers, or seeds). In myrtle (Vicente et al., 2006) and *Mentha arvensis* (Misra and Srivastava, 2000) water stress exerted significant reductions in plant biomass, including plant height and leaf area, but it did not have, at least in the latter species, any significant effect on oil yield and composition. However, in *Artemisia annua*, it resulted in a shortening of plant height, but only when induced in the two weeks before harvest (Charles et al., 1993).

When yield is represented by seeds and fruits, it is very often mainly determined by photosynthesis occurring after flowering (Arnon, 1992), and water stress should therefore have more negative effects when experienced at that phase than at any other growth stage. A direct consequence is that all annual species that finish their growth cycles in summer could be seriously affected by water shortage at the seed-filling stage, a feature not rare in Mediterranean environments. Under such situations, emergency watering could be a great help to production.

In perennials grown under dry or semi-arid climates, the recourse to irrigation (better if coupled with N fertilization) should push production towards its highest levels, and therefore represent an effective technical choice to obtain abundant and homogeneous yields. This is, for example, the choice of many Mediterranean farmers who want to cultivate sage or oregano in open irrigated fields. In this case, the costs needed for such an operation (water supply and the setting of watering lines) must be justified by the higher prices obtained from the sale of the product.

Frequently, water is not readily available and the recourse to irrigation is too expensive; here, essential oil crops are grown under a dry regime. In this case, annual plants can only use the water stored in the soil after the autumn–winter rainfall, and perennials are restricted to one cutting, normally taken at flowering time. In intermediate cases, farmers let the crop grow without irrigation for most of its cycle, and perform an irrigation after the main cutting is taken (at flowering time); in this way, the plants are allowed to bear a second harvest during the year, formed by the leaves that have regrown after watering.

When the water supply is limited, irrigation may be used occasionally as an emergency intervention if water stress threatens intolerable injury to plants. Above all, it is used following little or no rainfall, or as a planned intervention scheduled for the more critical development stages of crops, namely, the phases in which a water deficit could exert the worst effects on yield. Because good crop establishment is crucial for the success of almost all perennial crops, including lavender, oregano, thyme, mint, and rosemary, watering soon after transplantation is considered an essential practice.

If in Mediterranean semi-arid environments irrigation exerts a strong positive effect on biomass yield, under different climatic conditions crop responses are not always so positive: a field trial in Saskatchewan on German chamomile, as an example, gave a surprisingly much higher herbage yield under dryland conditions than following recourse to irrigation (Wahab and Larson, 2002).

An overall increment in oil yield per area unit, due to the highest leaf production, was observed under irrigation in sage (Bezzi et al., 1992), even when the essential oil percentage was not affected. In mint, it has been noted that a controlled induction of water stress could even increase oil accumulation, without having any effect on oil composition (Simon, 1993). Many authors, however, call attention to a negative effect that irrigation could have on essential oil content, stressing the importance of proper water management on oil yields.

7.5 Mechanization and Harvest

Mechanization is one of the areas in which research is lacking, but in which there are the strongest opportunities to develop new techniques and facilities that may significantly reduce production costs. Studies regarding the mechanization of essential oil crops may be divided into three main sectors: seeding/transplanting operations, weeding, and harvest.

The first group of operations differs in importance according to the species grown; it is generally a crucial aspect for many annual species, especially those with smaller seeds, in which setting seed distribution to desired values is more difficult, and it is generally difficult to achieve the planned plant population. Furthermore, smaller seeds require more care in soil preparation, because an uneven distribution will generate inhomogeneity in stands and operational difficulties at harvest. An interesting experience comes from southern Italy, where chamomile was mechanically sown by distributing the seeds on the tractor tires; it was also performed in this way to benefit simultaneous soil compression. In perennials, specific studies have addressed the mechanical transplantation of sage and lavender (young rooted plants), *Iris pallida* (the rhizomes), and saffron (the bulbs) by means of different equipment obtained with small modifications to normally adopted machines (Caligani and Adamo, 1987).

Along with mechanical weeding, that has been discussed already in a previous section, harvest exerts a strong effect on yield, both from quantitative and qualitative points of view. In many cases, and for many essential oil crops, manual harvesting allows a more careful operation, and therefore a higher yield and quality level. However, it is a time-consuming and labor-intensive practice, and its costs may be prohibitive when cultivation is performed over large areas.

The scheduling and management of harvest are operations in which farmers must make crucial decisions that may dramatically alter the productive and qualitative results of essential oil crops, and many aspects of harvest management must be considered in order to achieve a satisfactory result. First, proper timing of such an operation is crucial, since it determines the age and the development stage of the harvested material. In oregano (Jerkovic et al., 2001) and rosemary (Nevo, 1998), it has been proven to significantly modify qualitative and quantitative traits, since a delay in harvesting may cause the plants to become woody, which would reduce their active ingredients.

Second, the intensity of cutting is especially important in essential oil crops harvested for their foliage: the maximum biomass yield is reached when the stems are cut as close as possible to the soil. However, if excessive, this cutting may injure axillary buds, limiting the plants' capability to regrow for further harvests (Fig. 17).

Fig. 17 Cutting should spare the regrowth capacity of plants. In the photo, the restarting of vegetation after cutting in *Artemisia abrotanum* L. (*Photo: A. Carrubba*)

Furthermore, too severe a cutting, which would result in a higher percentage of stems (that usually have a poorer quantity and quality of oil) with respect to leaves and shoots in the harvested material, may alter the chemical characteristics of the essential oil. In many perennials (such as mint, and sometimes sage or oregano), the crop is managed with the intention of executing more than one cutting. In cornmint, cases of six to seven cuttings taken throughout a cropping cycle 17–18 months long have been reported (Rajeswara Rao, 1999). Even if the subsequent harvests do not allow the same essential oil yield obtainable from the first (Piccaglia et al., 1993), and the chemical profile of the essential oil obtained from the different cuttings varies (Omer et al., 1994), the economical success of the cultivation may rely on the possibility of making more than one harvest. For this reason, the ability of the plant to regrow must be considered.

There are many examples of the machinery used to harvest essential oil crops, such as for oregano (Leto et al., 2002; Verlet, 1992), sage, lavender (Caligani and Adamo, 1987), and chamomile (Wahab and Larson, 2002) (Fig. 18). Results seem to vary with the dryness of the herb to be collected and the destination of the product: the herb picked up mechanically may tend to brown, which is unwanted if the product is destined for the herbal market, but less so if it is destined for the extraction of essential oils. Some simple adjustments may help when using mechanical equipment and solve many of the technical problems that may arise, e.g., choosing fast-growing genotypes, such as achieved in some selected *Salvia* hybrids (Dudai et al., 1999), or setting a proper arrangement of rows for plant populations (Caligani and Adamo, 1987).

Different methods are required for essential oil crops where specific parts such as seeds are harvested, rather than the leaves or entire plants. Coriander, fennel, anise, and dill are examples of such production. Here, the tendency of growers and breeders is oriented to the mechanization of harvest, by means of the equipment

Fig. 18 Mechanization is a necessity for modern essential oil crops growers. In the photo, a prototype of mower modified for harvesting of oregano (*Origanum vulgare* L. subsp. *hirtum* (Link) Ietswaart). (*Photo: A. Carrubba*)

normally used on farms. Difficulty may result from the indeterminate growth habit of many such herbs, which may cause the contemporary appearance of flowers, ripe and unripe seed on the same plant. In this case, the best recourse should be hand harvesting, picking up the seeds (or umbels) as soon as they are marketable. Obviously, this is time and labor intensive, and many techniques and facilities for mechanical harvesting have been developed. Coriander and fennel, for example, may be cut to ground level and after some hours of open-air drying, be threshed mechanically.

7.6 Diseases and Pest Control

Pathogens and pests may cause considerable losses to the yield and quality of essential oil crops. Generally speaking, this topic has not been debated in depth in terms of essential oil crops, and until a few years ago, a widespread idea was that most such crops had no serious pests or diseases (Simon et al., 1984). More probably, the lack of information regarding this issue was mostly due to the limited cropping area of essential oil crops. In fact, the sources of information related to the diseases of essential oil crops were mostly limited to areas in which their cultivation reached appreciable levels. For example, in the 1980s, an infestation of *Ramularia coriandri* was found in coriander cultivations in the former Soviet Union (Gabler, 2002), and it forced growers and researchers to concentrate (successfully) their efforts towards the breeding and selection of resistant genotypes. Similar histories may be found in the literature for other crops and other pathogens, such as stem necrosis in fennel caused by *Phomopsis foeniculi* (Anzidei et al., 1996; Mugnai and Anzidei, 1994), sweet basil wilt caused by *Fusarium oxysporum* (Dudai et al., 2002), coriander and caraway foliar necrosis caused by *Ascochyta* and *Aureobasidium* sp. (Anonymous, 2002), rosemary root rot caused by *Rhizoctonia solani* and *Sclerotinia* sp. (Conway et al., 1997; Mohan, 1994), laurel leaf blight caused by *Glomerella cingulata* (Constantinescu and Jonsson, 1987), and mint leaf rust caused by *Puccinia menthae* (Joy et al., 2001).

Research concerning insects is also scarce in this context: red scale (*Aonidiella aurantii*) and several mealybugs have been reported to be common insect pests of jasmine, whereas hairy caterpillars, cut worms, semi-loopers, red pumpkin beetle, and termites have been observed in cultivations of Mint (*Mentha arvensis* L.) and controlled by means of suitable insecticides (Joy et al., 2001) (Fig. 19). However, the belief in the insecticidal effectiveness of many essential oil crops is so strong that some, such as *Artemisia vulgaris*, *Ocimum basilicum*, and *Mentha cordifolia,* have been suggested as intercrop species to repel insects from the main crop (IIRR, 1993).

A growing presence of insects on crops is a source of risk. Other than their direct damage to crops, they have a well-known ability to transmit dangerous viruses and viroids that in the specific case of essential oil crops could injure plants both from a quantitative and qualitative point of view. A survey of the virus diseases of some essential oil crops was carried out in Italy by Bellardi and Rubies-Autonell (2003), where 12 different virus strains affecting about 40 species were detected. According to the authors, damage was not only on plant biomass, but also on essential oil production and composition. For example, oil production from clary sage infected by Broad Bean Wilt Virus serotype I (BBWV-1) was one-third of that obtained from healthy plants, with an increased content in α-terpineol, germacrene D, and sclareol, and a lower percentage of myrcene and limonene.

An increase in pathogens and pests in essential oil crops, however, may be expected to be a direct consequence of the growing rate of cultivation (Gabler,

Fig. 19 Pests may have some impact on essential oil crops cultivation. In the photo: a young plant of clary sage (*Salvia sclarea* L.) with evident symptoms of attack by mites (*Acari*). (*Photo: A. Carrubba*)

2002), and it is possible to foresee that if essential oil monocultures spread over wider areas, such problems will become a major concern in the future. Experiments aimed at evaluating insecticides and pesticides useful for essential oil crop cultivation could certainly be performed, but the specific orientation of markets and the high "naturality" content of such products implies special care in their field management. The general tendency in cultivation of such crops is therefore oriented to their organic or integrated management, as also expressly suggested for extracts destined for the pharmaceutical industry or human therapy by the WHO guidelines on Good Agricultural and Collection Practices (GACP) for medicinal plants. Such guidelines imply the use of agrochemicals at the minimum possible level and "only when no alternative measures are available" (WHO, 2003).

With the purpose of improving general plant health conditions, many strategies have been recently developed. These include the employment of, and increase in, natural mycorrhization under many different agricultural environments (Kothari et al., 1999). Many essential oil crops have proven highly suitable to vesicular arbuscular mycorrhizal (VAM) fungal colonization, achieving a high percentage of internal infection (Camprubi et al., 1990), and some species (*Salvia officinalis, Lavandula officinalis*, and *Thymus vulgaris*) have been successfully used as indirect inoculation media to increase VAM root colonization of other tree species (Camprubi et al., 1992) (Fig. 20).

Another relevant concern is tied to the occurrence of pathogens, such as molds, on harvested and stored plant material. Usually, the use of proper storage conditions in clean and well-aerated places, and avoiding any possible retention of moisture in containers and contamination with insects, rodents, or other pests, should be enough to ensure the long-term conservation of plant material.

7.7 Postharvest Treatments

For quality features, postharvest treatments also play a crucial role. Depending on the species, the herb part used, the harvest timing and conditions, the water amount in herbs ranges from 40% to 80%. Some differences in essential oil characteristics have been claimed between dry and fresh plant material (Cioni et al., 1991; Shalaby et al., 1995), but drying is often necessary to increase the shelf life of the final product, to allow proper conditions for storage, and for the long-distance transport of the harvested product. Drying acts by slowing the growth of microorganisms and preventing some biochemical reactions that may alter the organoleptic characteristics of the herb (Díaz-Maroto et al., 2003).

In earlier times, most research papers available on this topic referred mostly to drying methods. This was in relation to the kind of material to be dried (tubers, roots, leaves, and bark), rather than to the different species (Chiumenti and Da Borso, 1996). More recently, many trials have been performed to find the best drying technique for most herbs, and it is certainly possible to find among them the best technique for the chosen environment and species.

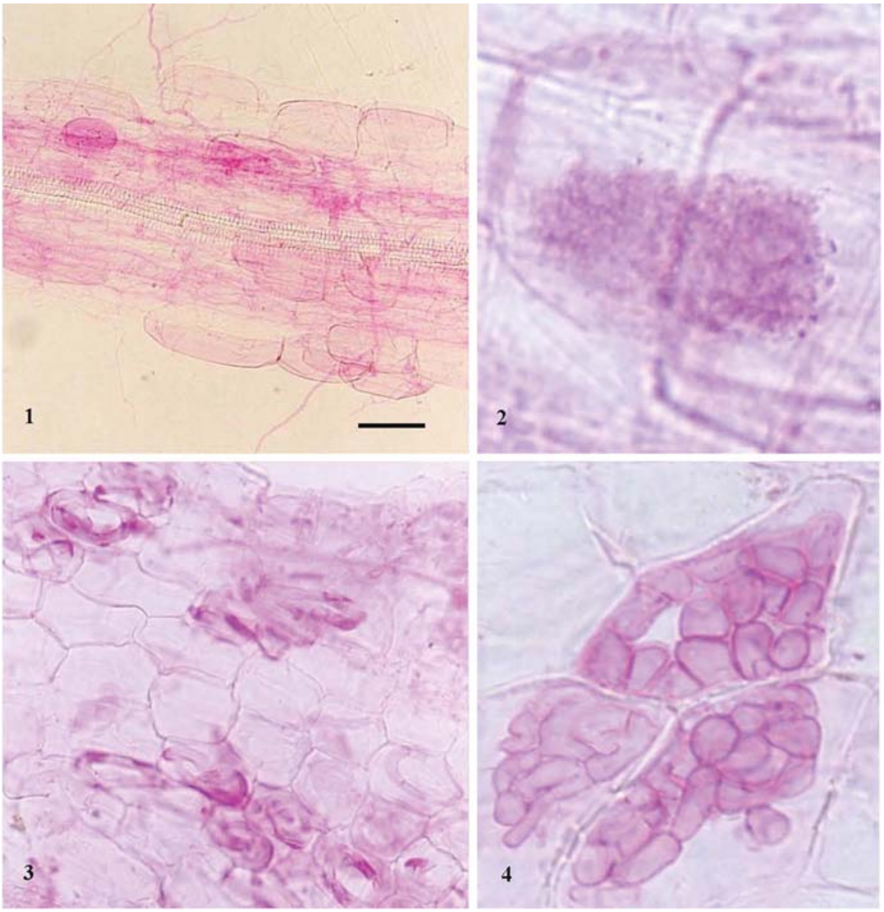

Fig. 20 Mycorrhization has been studied for many essential oil plants. In the photo, from left to right, examples of AM association in essential oil plants: (1) intra- and extramatrical structures of AM fungi and (2) arbuscule in basil root; (3) hyphal coils in cortical cells of lavander root; (4) myceliar structure in cortical cells of laurel root. Bar: 1, 3 = 30 μm; 2, 4 = 10 μm. (*Photo: L. Torta*)

There is no standard method for drying herbs, and each individual grower has often developed his own system, choosing from among the numerous methods that have been suggested, from air-drying to oven, microwave, or freezing systems. Each method has advantages and disadvantages, and the choice (besides the economic aspects) mostly relies on the desired result (texture, color, or scent) of the final product, and, of course, the requirements of its market destination. Method, duration, and temperature of drying, moreover, can affect the volatile oil content of the herb, which is a crucial factor in its quality. Such effects may vary according to the chosen plant material: in dill and parsley, oven- and freeze-drying lead to significant losses of volatiles with respect to fresh herbs, whereas such techniques exert a lower effect in sage and thyme (Díaz-Maroto et al., 2003). In the latter species, freeze-drying was found to produce oil yields about 10% higher than after a flow-through method (Lawrence, 1998).

An important target of research activity is to find, for each species, the maximum temperature for drying, in order to maximize volatile oil yield and quality. Generally, the higher the drying temperature, the greater the killing effect on microorganisms. However, a thermal excess could seriously damage the quality of essential oil; in thyme and sage, oven-drying induced lower losses of volatiles at 30°C and higher losses at 60°C (43% in thyme and 31% in sage with respect to the fresh herb) (Díaz-Maroto et al., 2003), whereas in French tarragon, the best oil retention was obtained at a working temperature of 45°C (Arabhosseini et al., 2007). In some cases, more attention is required on the duration of heat exposure than on the final temperature. For example, Charles et al. (1993) found that a treatment at 80°C for 12h had approximately the same effect on the artemisinin content of *Artemisia annua* as exposure to a much lower temperature (50°C) for a longer time (48 h).

The most ancient and traditional drying system is air-drying, which is performed outdoor (in warmer environments) or indoor (when external climatic conditions are not optimal and adequate structures are available). Many crops, such as mint and sage, may be successfully dried in plastic-covered greenhouses. Usually, the process involves stacking flat trays of herbs in the shadows (direct light may often alter the color of the product) and in aired places, sometimes with the help of dehumidifiers or forced circulating air equipment. Air-drying is a slow and labor-intensive process (there is the need to often move the mass to exsiccate so as to avoid brownish, fermentations and microbial attacks), but many experiments (Charles et al., 1993) have demonstrated that it allows the best results in terms of product quality.

Solar drying has been successfully tried in many environments (Buckenhüskes et al., 1996; Charles et al., 1993; Garg et al., 1998), and it has proven to give better color, texture, and content of active ingredients than conventional stove driers. Much equipment is available, is easy to set up, and can quickly dry large amounts of different plant material. Traditionally, such equipment has always been cheap, but nowadays problems have arisen due to quality control requirements and the need to reduce the bacterial count. When more sophisticated machinery (such as dehydration machines) is necessary, herb drying starts to become more capital intensive and the cost of equipment is often too high for many herb growers.

8 Conclusion

Plants producing aromatic oils have been used for flavoring throughout history. Many of them have formed part of the economy of countries with growing populations where there is an inevitable pressure on agricultural land as a resource for food and fuel crops. Many species for essential oil production might have direct interest as crop species for Mediterranean areas. Although some are native to Mediterranean

Fig. 21 Mixed cropping systems including essential oil crops may enhance farm productivity and biodiversity level. In the photo: oregano (*Origanum vulgare* ssp. *hirtum* (Link) Ietswaart) in association with young olive trees. (*Photo: M. Militello*)

environments, others are from different areas of the world, yet targeted to a growing interest as food or flavoring items. Most of the aforementioned herbs, especially those that are native, are easily grown and adapted to a wide variety of soil and climatic conditions. Therefore, they have already been cultivated by many farmers at a small scale, mostly for domestic or local use.

Currently, problems with essential oil crop production are above all commercial, linked to the establishment of market channels, to their high investment costs, and to the rapid expansion of competitive production from developing countries. In Mediterranean environments, such problems often add to general marginality conditions, requiring appropriate and well-constructed land management (Fig. 21).

Notwithstanding, today, a considerable pressure is exerted by consumers worldwide, to use perceived natural compounds in edible and personal products, and many opportunities seem therefore to be open for such crops. It is essential that producers are able to service this growing demand efficiently, economically, and above all, reliably. It is therefore important to understand and develop ways of ensuring maximum return on the investments made in establishing and growing these crops (Weiss, 1997). The great amount of experimental research carried out worldwide has brought important advances to cropping techniques. In some cases, it has improved the plant material available for cultivation, although its availability to growers is far from satisfactory. Much work still remains to be done to further advance the techniques required for the special environmental conditions of Mediterranean environments, and for the wider application of such techniques and improvement of genetic materials available to farmers.

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